Geomechanics and Engineering, *Vol. 5, No. 4 (2013) 363-377*
DOI: http://dx.doi.org/10.12989/gae.2013.5.4.363

Experimental estimate of $N\gamma$ values and corresponding settlements for square footings on finite layer of sand

Manish S. Dixit* and Kailas A. Patil[a]

Department of Civil Engineering, Government College of Engineering, Aurangabad (Maharashtra State), India, 431 005

(Received July 31, 2012, Revised February 15, 2013, Accepted April 05, 2013)

Abstract. Any structure constructed on the earth is supported by the underlying soil. Foundation is an interfacing element between superstructure and the underlying soil that transmits the loads supported by the foundation including its self weight. Foundation design requires evaluation of safe bearing capacity along with both immediate and long term settlements. Weak and compressible soils are subjected to problems related to bearing capacity and settlement. The conventional method of design of footing requires sufficient safety against failure and the settlement must be kept within the allowable limit. These requirements are dependent on the bearing capacity of soil. Thus, the estimation of load carrying capacity of footing is the most important step in the design of foundation. A number of theoretical approaches, in-situ tests and laboratory model tests are available to find out the bearing capacity of footings. The reliability of any theory can be demonstrated by comparing it with the experimental results. Results from laboratory model tests on square footings resting on sand are presented in this paper. The variation of bearing capacity of sand below a model plate footing of square shape with variation in size, depth and the effect of permissible settlement are evaluated. A steel tank of size 900 mm × 1200 mm × 1000 mm is used for conducting model tests. Bearing capacity factor N_γ is evaluated and is compared with Terzaghi, Meyerhof, Hansen and Vesic's N_γ values. From the experimental investigations it is found that, as the depth of sand cushion below the footing (D_{sc}) increases, ultimate bearing capacity and settlement values show an increasing trend up to a certain depth of sand cushion.

Keywords: square footing; model test; sand; depth; ultimate bearing capacity; settlement

1. Introduction

Among several different approaches in determination of the bearing capacity of shallow foundations, the famous triple-N formula of Terzaghi has been generally employed in the past decades, and can be written as given in Eq. (1).

$$q_{ult} = cN_c + qN_q + 0.5\gamma BN_\gamma \tag{1}$$

where, q_{ult} is the bearing capacity of soil mass, c is the cohesion, q is the surcharge pressure, B is

*Corresponding author, Ph.D. Student, E-mail: manishsdixit@gmail.com
[a] Associate Professor, E-mail: kapatil67@gmail.com

http://www.techno-press.org/?journal=gae&subpage=7 ISSN: 2005-307X (Print), 2092-6219 (Online)

the foundation width and γ is the unit weight of soil mass. Similarly N_c, N_q and N_γ are bearing capacity factors, which are functions of the soil friction angle. The second and third terms in Eq. (1) have been known as the main contributor to the bearing capacity of shallow foundations on non-cohesive soils. There are several suggested values for the third factor by different investigators such as Terzaghi (1943), Meyerhof (1963), Hansen (1970), Vesic (1973), Bolton and Lau (1989) etc. Although all these methods are generally based on a limit analysis solution, there are differences between their assumptions for boundary conditions and consideration of the soil weight effect. The third bearing capacity factor i.e., N_γ has been computed by taking several assumptions in to account. Terzaghi (1943) assumed that, the components of bearing capacity equation can be safely superposed. Bolton and Lau (1989) performed a study on the effect of surcharge pressure on computed N_γ and presented a dimensionless factor Ω defined as the ratio of the surcharge pressure q to γB. They stated that if this factor is equal to or less than 1.0, the effect of surcharge pressure leads to less than 20% error in calculation of the bearing capacity factor (N_γ), which seems to be acceptable for practical purposes. Beside these assumptions, almost all conventional methods assume a constant value of soil friction angle to compute the bearing capacity factors.

Considering the bearing capacity equation, the third term suggests an increasing tendency in bearing capacity with an increase in foundation size. However, data from De Beer (1965), Bolton and Lau (1989) shows that the bearing capacity of shallow foundations does not increase with size linearly and the bearing capacity factor N_γ, decreases by increasing foundation size.

2. Earlier studies carried out

A shallow foundation is load carrying structures that transmit loads directly to the underlying soil. Shallow is a relative term, a foundation with a depth to width ratio less than or equal to four ($D/B \leq 4$) is simply called a shallow foundation (Das 1999). A foundation must satisfy two fundamental requirements: ultimate bearing capacity and settlement of foundations. The bearing capacity of soil can be defined as the foundation's resistance when maximum pressure is applied from the foundation to the soil without arising shear failure in the soil. The load per unit area of the foundation at which shear failure takes place is called the ultimate bearing capacity. By taking into account these two criteria, there are many theories and many approaches in laboratory and in situ studies to determine the ultimate bearing capacity. Firstly, Prandtl (1921), and thereafter Reissner (1924) presented theories based on the concept of plastic equilibrium. Later, the formulation was modified by Terzaghi (1943), Meyerhof (1963), Hansen (1970), Vesic (1973) and others.

The ultimate bearing capacity depends on the size of the foundation for both square and rectangular footings. Therefore, small models of footings prepared in a laboratory are different from real size footings with regards to behavior and stress distribution. This is called the scale effect, and it has been studied by numerous researchers for many years (Bolton and Lau 1989, Cerato 2005, Kumar and Khatri 2008, Veiskarami *et al*. 2011). The scale effect arising from the grain size of the soil has a significant role if the foundation width to grain size ratio is less than 50-100. Therefore, caution must be taken in applying the results of very small-scale model footing tests instead of full-scale behaviors. One simple solution to solve possible problems due to the scale effect is to use a larger footing, giving an acceptable size ratio, B/D_{50} greater than 100 (Taylor 1995). Although it is necessary to test the actual size footing to understand real soil foundation behavior to do so is an expensive, time consuming and experimentally difficult process. For this reason, taking the scale effect into consideration most researchers have only worked on small-scale footings of different sizes in the laboratory to obtain the ultimate bearing capacity.

Terzaghi (1943) formed a semi-empirical equation for computing the ultimate bearing capacity of a foundation. Later, Meyerhof (1963) proposed a general bearing capacity equation similar to that of Terzaghi which included different shape and depth factors. He took into account the shear strength of the soil above the base level of the footing. Thereafter, Hansen (1970) modified the study of Meyerhof (1963), Vesic (1973) used an equation very similar to that suggested by Hansen (1970). However, there are some restrictions and assumption in all of these classical formulations; therefore, they do not always give reasonable results compared to available experimental data. Because of the uncertain nature of soils and the difficulties of experimental tests in laboratory and in situ, there is an increasing tendency to seek alternative bearing capacity prediction methods, other than the traditional computing techniques, to obtain more accurate results.

3. Experimental study

3.*1 Materials used for the testing: sand*

The test sand used in this study was dry sand collected from Godavari River near Paithan about 50 km from Aurangabad in Maharashtra State of India. The aim of this work is to study the effect of variation in size, depth of sand cushion below the footing (D_{sc}) and permissible settlement of footing on bearing capacity of sand for square footing. The specific gravity of sand is found to be 2.65, coefficient of uniformity (C_u) 3.20, coefficient of curvature (C_C) 0.96 and effective particle size (D_{10}) 0.42 mm. Grain size distribution curve is shown in Fig. 1. The maximum and minimum

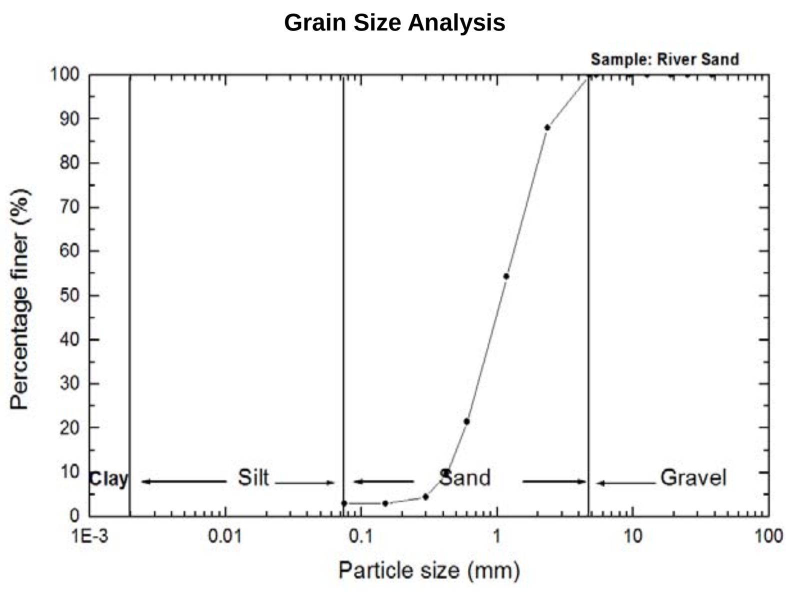

Fig. 1 Grain size distribution of sand

dry unit weights of the sand were determined according to IS: 2720(1983), (part 14). The maximum dry unit weight obtained is 18 kN/m³ and the minimum dry weight obtained by pouring into the loosest state is 15.3 kN/m³. The friction angle of the sand at 82.90% relative density (D_r), as determined from direct shear test on dry sand sample, is found to be 40°.

3.2 Laboratory model tests

3.2.1 Test set-up

The load tests were conducted in a rectangular steel tank of 900 mm × 1200 mm in plan and 1000 mm in depth. The model footings used for the tests were square in shape. The footings were made of 10 mm thick rigid steel plate of sizes 100 mm × 100 mm, 120 mm × 120 mm, and 150 mm × 150 mm. A hydraulic jack attached to the proving ring was used to push the footing slightly into the bed for proper contact between the soil and footing. A schematic diagram of the test set-up is shown in Fig. 2. In the present study the intensity of loading will be denoted by q and depth of sand cushion below the footing will be denoted by $D_{sc.}$

3.2.2 Preparation of test bed

Pluviation i.e., raining technique was used to place the sand in test tank. The height of fall to achieve the desired relative density was determined by performing a series of trials with different heights of fall. In each trial, the densities were monitored by collecting samples in small aluminum cups of known volume placed at different locations in the test tanks, based on the minimum and maximum void ratios of the sand for each height of fall, the relation between the height of fall and the corresponding relative density was developed.

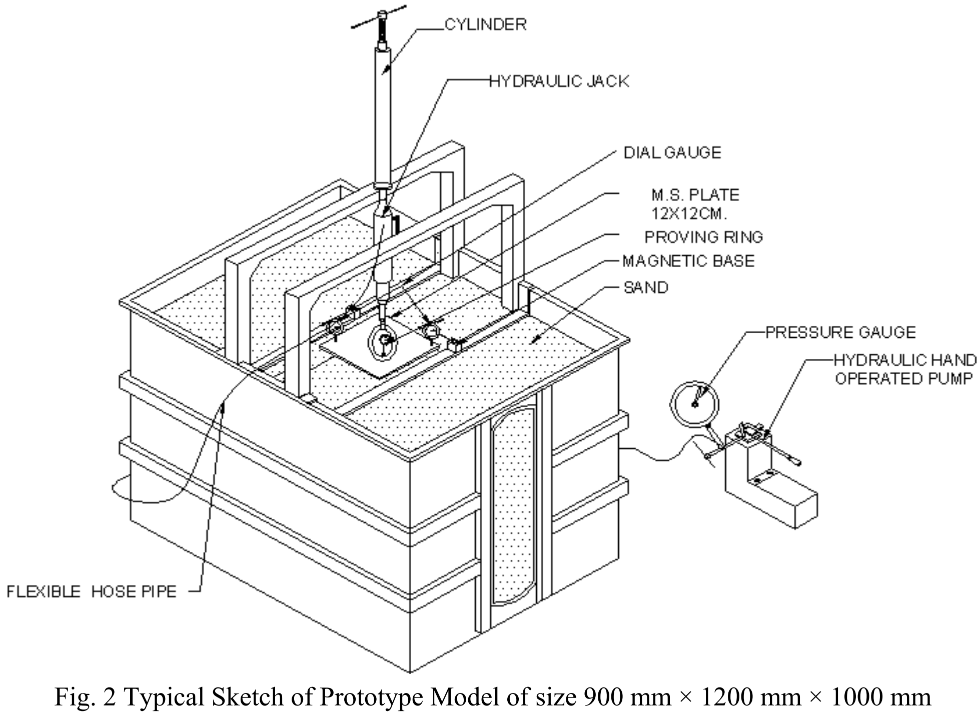

Fig. 2 Typical Sketch of Prototype Model of size 900 mm × 1200 mm × 1000 mm

3.2.3 Testing procedure

Initially the sand bed of 900 mm depth was prepared in the steel test tank using the sand raining technique. The side walls of the tank were made smooth by painting with an oil paint to reduce the boundary effects. After preparing the bed, the surface was levelled, and the footing was placed exactly at the centre of the loading jack to avoid eccentric loading.

The footing was loaded by a hand operated hydraulic jack supported against a reaction frame. A pre-calibrated proving ring was used to measure the load transferred to the footing. The load was applied in small increments. Each load increment was maintained constant until the footing settlement was stabilized. The footing settlements were measured through the dial gauges whose locations are shown in the Fig. 2. Table 1 shows the effect of intensity of loading on settlement at different depth of sand cushion below the footing (D_{sc}), for 100mm square plate.

Table 1 Effect of q and D_{sc} on settlement in mm, for 100 mm square plate

Intensity of loading (q) (kN/m²)	Depth of sand cushion below the footing (D_{sc}) in mm					
	900	750	600	450	300	150
0	0	0	0	0	0	0
20	0.8	0.72	0.7	0.68	0.52	0.44
40	2.39	2.1	2.08	2.04	1.7	1.51
60	4.78	3.98	3.93	4.16	4.36	3.46
80	7.94	6.05	6.31	6.91	6.45	6.16
100	9.54	7.67	7.94	8.31	7.94	7.70
120	11.48	9.55	9.55	10	9.74	8.31
140	13.48	11.5	11.35	11.48	10.96	9.12
160	15.13	13.5	13.18	13.18	12.02	9.77

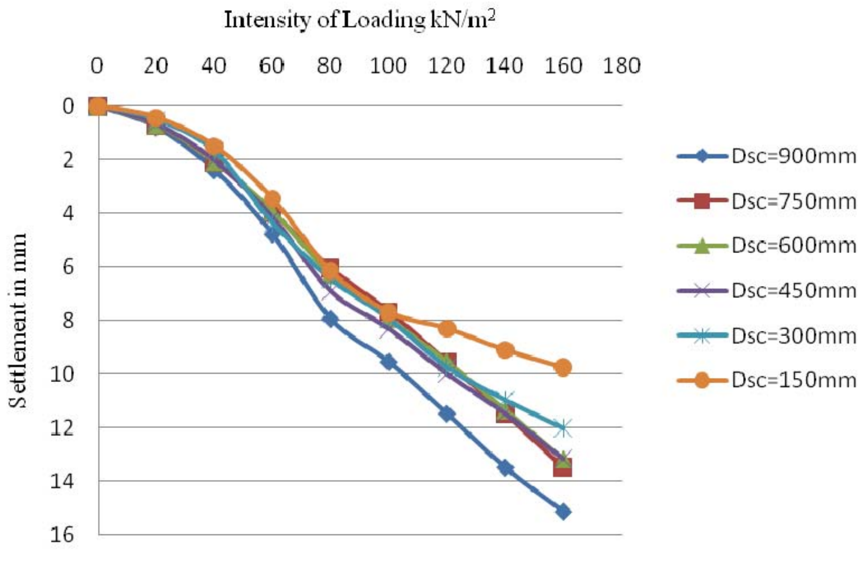

Fig. 3 Effect of loading intensity on settlement for different depths of sand cushion for 100 mm square plate

Fig. 3 shows the effect of intensity of loading on settlement for different depth of sand cushion below the footing (D_{sc}). It is also seen from Fig. 3 that, as the depth of sand cushion below the footing increases settlement also increases.

As shown in Figs. 4-5 log load vs log settlement relationship is plotted and two intersecting straight lines are identified in the data points. The load corresponding to point of intersection gives the ultimate bearing capacity and corresponding settlement is obtained. N_γ values are computed using the equation $q_{ult} = 0.4\gamma BN_\gamma$ and they are computed for various depths of sand cushion. The results are compared with the theoritical values proposed by Terzaghi (1943), Meyerhoff (1963), Hansen (1970) and Vesic (1973).

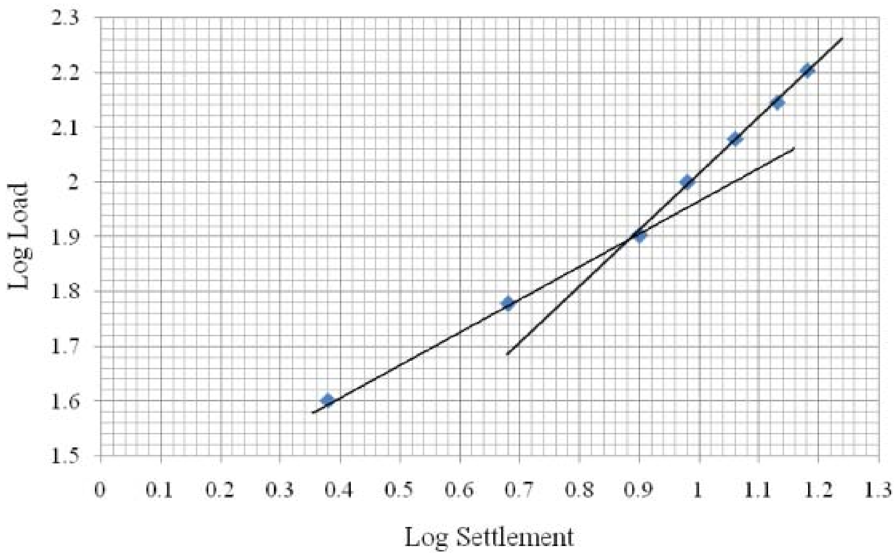

Fig. 4 Log load vs log settlement for 100 mm square plate (sand cushion depth 900 mm)

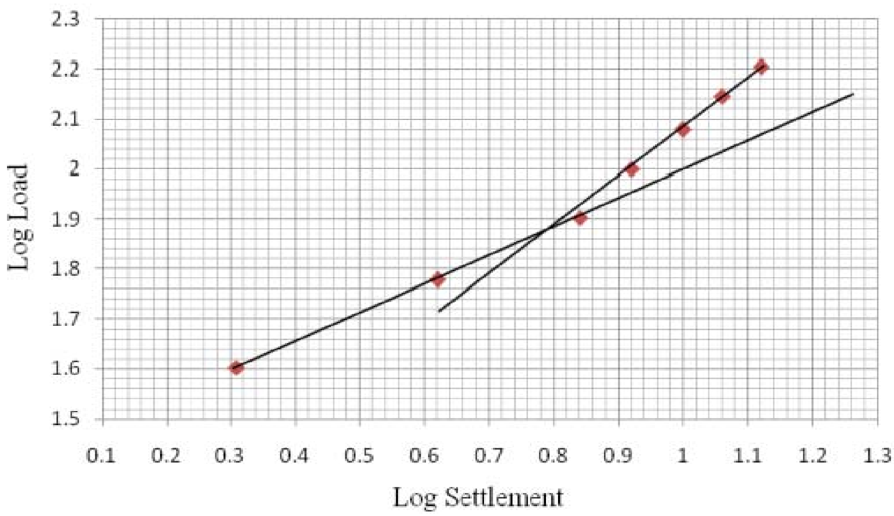

Fig. 5 Log load vs log settlement for 100 mm square plate (sand cushion depth 450 mm)

Table 2 Effect of D_{sc} for 100 mm square plate for log-log method and ultimate load corresponding to 10% of footing width and N_γ values

Sand cushion depth in mm	Ultimate load (kN/m^2)	Settlement in mm	N_γ values	Ultimate load (kN/m^2) corresponding to 10% of footing width	N_γ values
900	80.6	7.94	112.00	104	144.44
750	78.8	6.02	109.40	124	172.22
600	79.7	6.30	110.70	126	175
450	79.2	6.20	109.95	124	172.22
300	75.8	6.05	107.30	122	169.44
150	74.1	5.75	102.95	160	222.22

Table 3 Effect of q and D_{sc} on settlement for 120 mm square plate

Intensity of loading (q) (kN/m^2)	Depth of sand cushion below the footing (D_{sc}) in mm					
	900	750	600	450	300	150
0	0	0	0	0	0	0
13.88	1.03	0.92	0.89	0.8	0.68	0.54
27.77	3.24	3.06	3.02	2.9	2.5	2.2
41.66	5.45	4.84	4.78	4.66	4.4	4.08
55.55	7.9	7.2	7.1	7.02	6.8	6.52
69.44	10.4	9.62	9.52	9.4	8.9	8.52
83.33	12.9	12.08	11.9	11.78	10.96	10.4
97.22	15.38	14.6	14.48	14.39	13.6	13.18
111.11	17.9	17.02	16.9	16.8	15.34	14.4
125	20.14	18.96	18.76	18.68	16.9	15.1

Table 2 show the ultimate load corresponding to 10% of footing width and N_γ values for different depths of sand cushion below the footing for $\phi = 40°$. It is observed that the values of ultimate load corresponding to 10% of footing width lie in the range 104 to 160 kN/m^2. N_γ values lie in the range of 144.44-222.22 which are much higher as compared to log-log method. The values obtained by log load versus log settlement method fall in the range 100-112. For the same case the values of N_γ calculated by Terzaghi (1943), Hansen (1970), Vesic (1973), and Meyerhof (1963) methods are 115.31, 95.41, 109.41 and 95.4 respectively.

Table 3 shows the effect of intensity of loading on settlement at different depths of sand cushion below the footing (D_{sc}), for 120mm square plate. From the table it is found that as depth of sand cushion below footing increases settlement also increases.

Fig. 6 shows the effect of intensity of loading on settlement for different depth of sand cushion below the footing (D_{sc}). It is also seen from this figure that, as the depth of sand cushion below the footing increases settlement also increases.

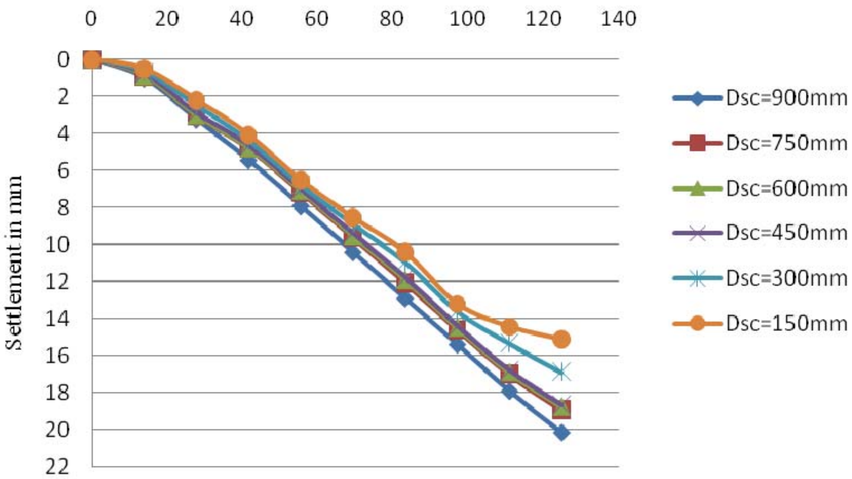

Fig. 6 Effect of loading intensity on settlement for different depths for 120 mm square plate

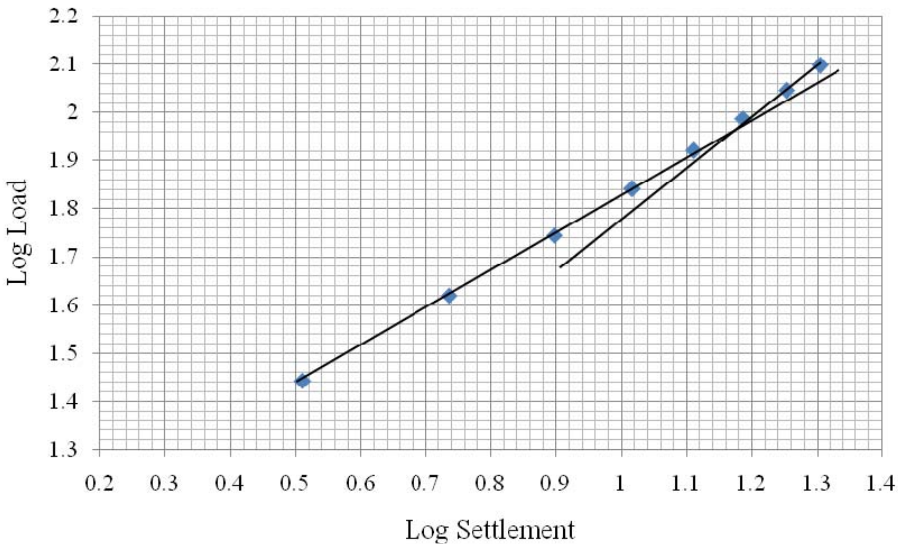

Fig. 7 Log Load vs Log Settlement for 120 mm Square Plate (sand cushion depth 900 mm)

Figs. 7-8 show log load vs log settlement curve. From these cuves ultimate load for individual cases are determined and which are tabulated in Table 4.

Table 4 shows the ultimate load corresponding to 10% of footing width and N_γ values for different depths of sand below the footing for $\phi = 40°$ It is observed that the values of ultimate load corresponding to 10% of footing width lie in the range 78 to 90 kN/m^2. N_γ values lie in the range of 90.27-104.17 which are lower as compared to log-log method. The values obtained by log load versus log settlement method fall in the range 100-118. For the same case the values of N_γ calculated by Terzaghi (1943), Hansen (1970), Vesic (1973), and Meyerhof (1963) methods are 115.31, 95.41, 109.41, and 95.4 respectively.

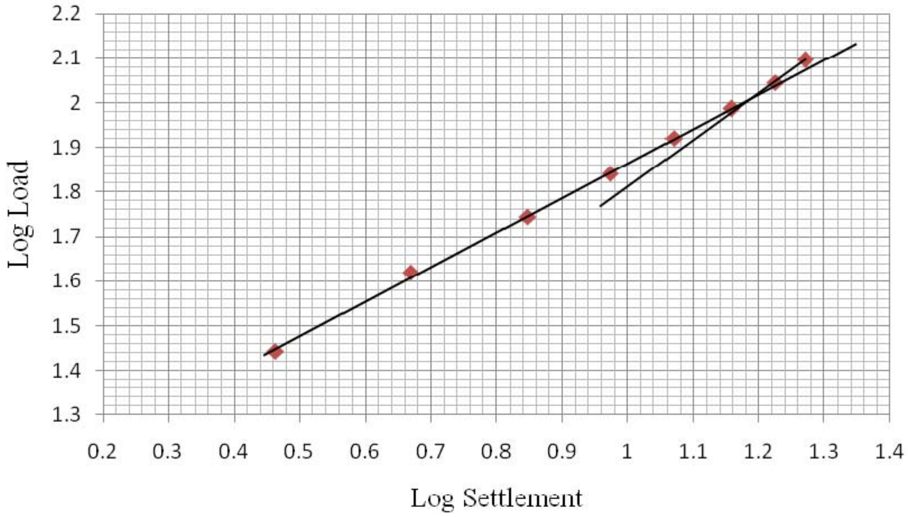

Fig. 8 Log Load vs Log Settlement for 120 mm Square Plate (sand cushion depth 450 mm)

Table 4 Effect of D_{sc} for 120 mm square plate for log-log method and ultimate load corresponding to 10% of footing width and N_γ values

Sand cushion depth in mm	Ultimate load (kN/m^2)	Settlement in mm	N_γ values	Ultimate load (kN/m^2) corresponding to 10% of footing width	N_γ values
900	91.20	15.13	105.55	78	90.27
750	100	15.13	115.74	84	97.22
600	102.32	15.84	118.43	85	98.38
450	100	15.13	115.74	85	98.38
300	91.20	13.18	105.55	88	101.85
150	87.09	12.58	100.80	90	104.17

Table 5 Effect of q and D_{sc} on settlement for 150 mm square plate

Intensity of loading (q) (kN/m²)	Depth of sand cushion below the footing (D_{sc}) in mm					
	900	750	600	450	300	150
0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.88	0.98	0.90	0.87	0.70	0.57	0.44
17.77	1.40	1.20	1.14	0.98	0.75	0.58
26.66	3.12	2.90	2.89	2.84	2.48	2.10
35.55	4.58	4.38	4.36	4.28	3.73	3.31
44.44	6.17	5.89	5.78	5.75	5.03	4.69
53.33	7.62	7.43	7.62	7.61	6.57	6.04
62.22	9.60	8.74	9.58	9.17	8.35	8.21
71.11	11.26	10.51	11.55	11.00	10.58	9.82

Table 5 Continued

Intensity of loading (q) (kN/m²)	Depth of sand cushion below the footing (D_{sc}) in mm					
	900	750	600	450	300	150
88.88	13.79	14.85	14.87	14.33	13.20	13.15
97.77	16.65	17.04	16.60	16.41	16.27	16.11
106.66	18.26	18.27	18.25	17.85	16.83	17.04
115.55	20.48	20.97	20.53	19.56	18.43	18.06
125.00	21.85	21.44	21.30	20.81	19.73	19.48
133.32	23.01	22.73	22.36	22.00	20.97	20.53
142.20	23.53	22.98	23.52	22.94	22.01	21.37
151.08	24.00	23.52	23.66	23.52	22.81	22.14
159.96	24.50	24.32	24.28	24.22	23.40	22.74

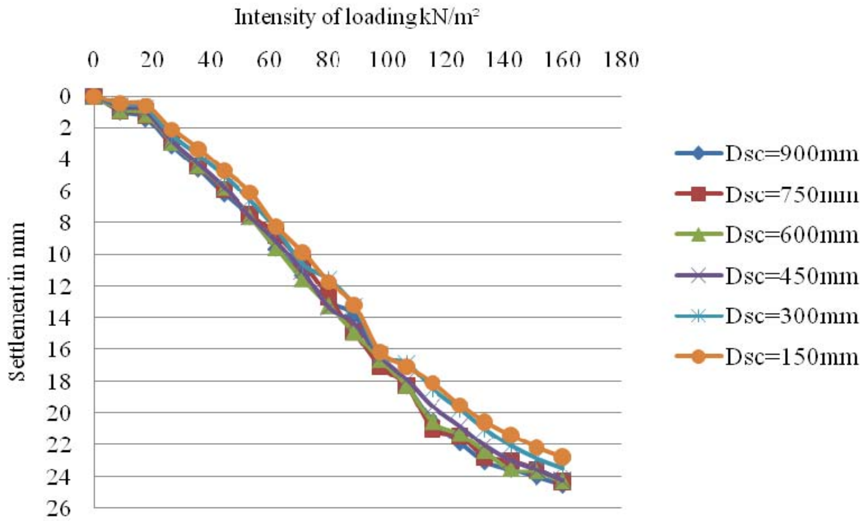

Fig. 9 Effect of loading intensity on settlement for different depths for 150 mm square plate

Fig. 9 shows the effect of intensity of loading on settlement for different depth of sand cushion below the footing (D_{sc}). It is also seen from Fig. 9 that, as the depth of sand cushion below the footing increases settlement also increases.

Figs. 10-11 show log load vs log settlement curve. From these cuves ultimate load for individual cases are determined and which are tabulated in Table 6.

Table 6 shows the ultimate load corresponding to 10% of footing width and N_γ values for different depths of sand below the footing for ϕ = 40°. It is observed that the values of ultimate load corresponding to 10% of footing width lie in the range 90 to 94 kN/m^2. N_γ values lie in the range of 83.33-87.04 which are lower as compared to log-log method. The values obtained by log load versus log settlement method fall in the range 94-107. For the same case the values of N_γ

calculated by Terzaghi (1943), Hansen (1970), Vesic (1973), and Meyerhof (1963) methods are 115.31, 95.41, 109.41, and 95.4 respectively.

Table 7 shows the effect of plate size for different depth of sand cushion below the footing on N_γ values. It is seen that log-log method gives better results as compared to ultimate load corresponding to 10% of footing width.

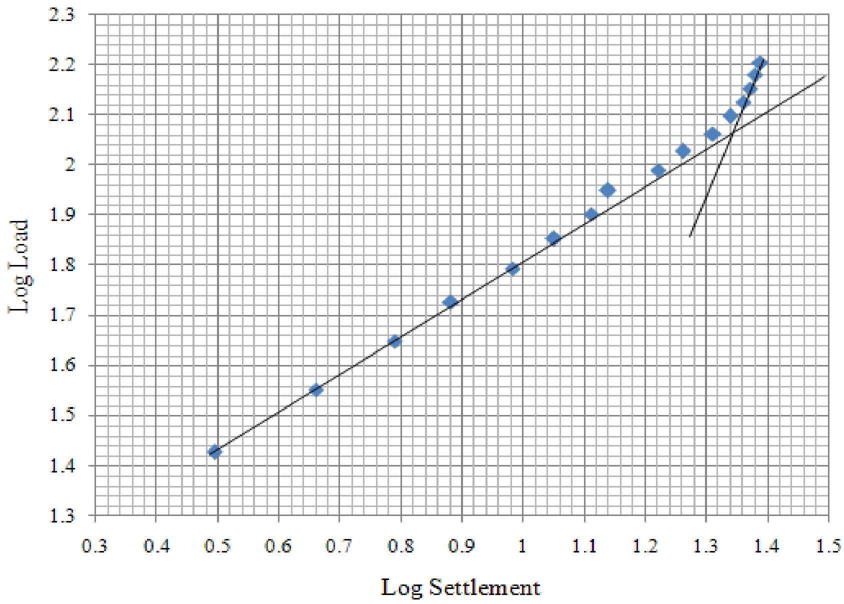

Fig. 10 Log Load vs Log Settlement for 150 mm Square Plate (sand cushion depth 900 mm)

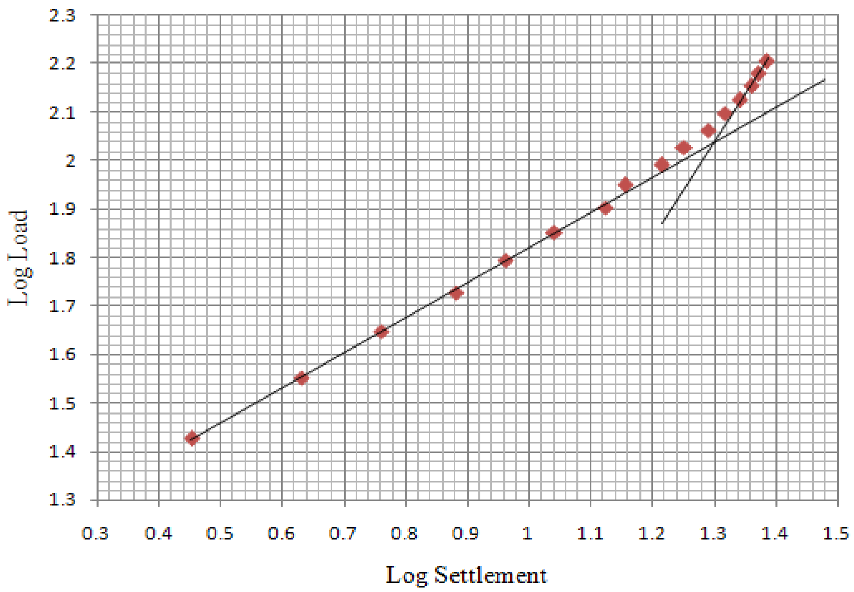

Fig. 11 Log Load vs Log Settlement 150 mm Square Plate (sand cushion depth 450 mm)

Table 6 Effect of D_{sc} for 150 mm square plate for log-log method and ultimate load corresponding to 10% of footing width and N_γ values

Sand cushion depth in mm	Ultimate load (kN/m^2)	Settlement in mm	N_γ values	Ultimate load (kN/m^2) corresponding to 10% of footing width	N_γ values
900	115.95	21.87	107.36	94	87.04
750	112.62	20.89	104.27	90	83.33
600	110.94	20.89	102.72	90	83.33
450	109.86	19.95	101.72	92	85.19
300	105.47	18.19	97.65	94	87.04
150	102.38	17.37	94.79	94	87.04

Table 7 Effect of Plate Size for different D_{sc} on N_γ values

Sand cushion depth in mm	N_γ values					
	100 mm		120 mm		150 mm	
	Log-log method	10% of footing width	Log-log method	10% of footing width	Log-log method	10% of footing width
900	112.00	144.44	105.55	90.27	107.36	87.04
750	109.40	172.22	115.74	97.22	104.27	83.33
600	110.70	175	118.43	98.38	102.72	83.33
450	109.95	172.22	115.74	98.38	101.72	85.19
300	107.30	169.44	105.55	101.85	97.65	87.04
150	102.95	222.22	100.80	104.17	94.79	87.04

4. Results and discussion

For depth of sand cushion of 900 mm for square plate of sizes 100 mm, 120 mm and 150 mm, ultimate bearing capacity values are found to be 80.6 kN/m², 91.20 kN/m² and 115.95 kN/m² respectively. As compared to 100 mm square plate, the percentage increase in the ultimate bearing capacity for 120 mm and 150 mm square plates are found to be 13.15% and 43.85% respectively. Thus it indicates that as plate size increases, ultimate bearing capacity goes on increasing for log-log method where as ultimate load corresponding to 10% of the footing width are found to be 104 kN/m²,78 kN/m² and 94 kN/m².

For depth of sand cushion of 750 mm for square plate of sizes 100 mm, 120 mm and 150 mm, ultimate bearing capacity values are found to be 78.8 kN/m², 100 kN/m² and 112.62 kN/m² respectively. As compared to 100 mm square plate, the percentage increase in the ultimate bearing capacity for 120 mm and 150 mm square plates are found to be 26.90% and 42.91% respectively for log-log method where as ultimate load corresponding to 10% of the footing width are found to be 124 kN/m², 84 kN/m² and 90 kN/m².

For depth of sand cushion of 600 mm for square plate of sizes 100 mm, 120 mm and 150 mm, ultimate bearing capacity values are found to be 79.7 kN/m², 102.32 kN/m² and 110.94 kN/m² respectively. As compared to 100 mm square plate, the percentage increase in the ultimate bearing capacity for 120 mm and 150 mm square plates are found to be 28.38% and 39.19% respectively for log-log method where as ultimate load corresponding to 10% of footing width values are found to be 126 kN/m², 85 kN/m² and 90 kN/m² respectively.

For depth of sand cushion of 450 mm for square plate of sizes 100 mm, 120 mm and 150 mm, ultimate bearing capacity values are found to be 79.2 kN/m², 100 kN/m² and 109.86 kN/m² respectively. As compared to 100mm square plate, the percentage increase in the ultimate bearing capacity for 120 mm and 150 mm square plates are found to be 26.26% and 38.7% respectively for log-log method where as ultimate load corresponding to 10% of footing width values are found to be 124 kN/m², 85 kN/m² and 92 kN/m² respectively.

For depth of sand cushion of 300 mm for square plate of sizes 100 mm, 120 mm and 150 mm, ultimate bearing capacity values are found to be 75.85 kN/m², 91.20 kN/m² and 105.47 kN/m² respectively. As compared to 100 mm square plate, the percentage increase in the ultimate bearing capacity for 120 mm and 150 mm square plates are found to be 19.46% and 39.05% respectively for log-log method where as ultimate load corresponding to 10% of footing width values are found to be 122 kN/m², 88 kN/m² and 94 kN/m² respectively.

For depth of sand cushion of 150mm for square plate of sizes 100 mm, 120 mm and 150 mm, ultimate bearing capacity values are found to be 74.1 kN/m², 87.09 kN/m² and 102.38 kN/m² respectively. As compared to 100 mm square plate, the percentage increase in the ultimate bearing capacity for 120 mm and 150 mm square plates are found to be 17.53% and 38.16% respectively for log-log method where as ultimate load corresponding to 10% of footing width values are found to be 160 kN/m², 90 kN/m² and 94 kN/m² respectively.

For square plate of size 100 mm and depth of sand cushion below the footing of 750 mm, 600 mm and 450 mm, the values of settlements are found to be nearly same. Similar trend is observed for square plate of sizes 120 mm and 150 mm. For depth of sand cushion below the footing 300 mm and 150 mm, the bottom of the tank is nearer to the loaded plate. As the bottom of the tank is fairly rigid hence lower values of settlement are observed for log-log method. Similar trend is observed for ultimate load corresponding to 10% of footing width. In general it is observed that log-log method gives a better estimate of ultimate load as compared to the other method.

The values of N_γ obtained from experimental investigations for square plate of size 100 mm for various depths of sand cushion show lower bound values in comparison with Terzaghi's method (1943). Hansen's (1970) and Meyerhof's methods (1963) show upper bound values for various depths of sand cushion. Vesic's method (1973) for 900 mm depth of sand cushion shows upper bound values and for depths 750 mm, 600 mm and 450 mm, the values are approximately same. For 300 mm and 150 mm depth of sand cushion shows lower bound values. The values of N_γ obtained for ultimate load corresponding to 10% of footing width show upper bound values for all the depths.

The values of N_γ obtained from experimental investigations for square plate of size 120 mm for various depths of sand cushion i.e., 900 mm, 300 mm and 150 mm, show lower bound values in comparison with Terzaghi's method (1943). For 750 mm, 600 mm and 450 mm depths of sand cushion, the values are approximately same in comparison with Terzaghi's method (1943). The values of N_γ obtained from experimental investigations for square plate of size 120 mm for various depths of sand cushion i.e., 900 mm, 300 mm and 150 mm, show lower bound values in comparison with Vesic's method (1973). For 750 mm, 600 mm and 450 mm depths of sand cushion, the values are approximately same in comparison with Vesic's method (1973). The values of N_γ obtained from experimental investigations for square plate of size 120 mm for various depths of sand cushion show upper bound values in comparison with Hansen's (1970) and Meyerhof's methods (1963). The values of N_γ obtained for ultimate load corresponding to 10% of footing width show lower bound values for Terzaghi (1943) and Vesic method (1973) where as for Hansen (1970) and Meyerhof method (1963) show upper bound values.

The values of N_γ obtained from experimental investigations for square plate of size 150 mm for various depths of sand cushion show lower bound values in comparison with Terzaghi's method (1943). The values of N_γ obtained from experimental investigations for square plate of size 150 mm for various depths of sand cushion show lower bound values in comparison with Vesic's method (1973).

The values of N_γ obtained from experimental investigations for square plate of size 150 mm for various depths of sand cushion show upper bound values in comparison with Hansen's (1970) and Meyerhof's methods (1963). The values of N_γ obtained for ultimate corresponding to 10% of footing width show lower bound values for all the depths.

It is observed that when the depth of sand cushion is more than 3 times the footing width there is no influence on the ultimate load and settlements of the footing.

5. Conclusions

Based on the studies carried out the following conclusions are drawn.

- For square plates of size 100 mm, 120 mm and 150 mm with depth of sand cushion of 900 mm, ultimate bearing capacity values are found to be 80.6 kN/m², 91.20 kN/m² and 115.95 kN/m² respectively. Thus it indicates that as plate size increases, ultimate bearing capacity goes on increasing for log-log method. For ultimate load corresponding to 10% of footing width, the bearing capacity decreases as the cushion thickness increases.
- For square plate of size 100 mm and depth of sand cushion below the footing of 750 mm, 600 mm and 450 mm, the values of settlements are found to be nearly same. Similar trend is observed for square plate of sizes 120 mm and 150 mm. For depth of sand cushion below the footing 300 mm and 150 mm, as the bottom of the tank is rigid, settlement is considerably reduced.
- The values of N_γ obtained from experimental investigations for square plate of size 100 mm for various depths of sand cushion show lower bound values in comparison with Terzaghi's method. Hansen's and Meyerhof's methods show upper bound values for various depths of sand cushion. Vesic's method for 900 mm depth of sand cushion shows upper bound values and for depths 750 mm, 600 mm and 450 mm, the values are approximately same. For 300 mm and 150 mm depth of sand cushion shows lower bound values. Similar trend is observed for square plate of sizes 120 mm and 150 mm.
- Log-log method gives better results as compared to ultimate load corresponding to 10% of footing width. The values of N_γ obtained by log-log method are closer to the values given by Terzaghi (1943), Meyerhof (1963), Hansen (1970) and Vesic (1973).
- For depth of sand cushion of 750 mm, 600 mm and 450 mm ultimate load values are nearly same by log-log method and ultimate load corresponding to 10% of the footing width.
- The bearing capacity factor N_γ decreases by increasing the footing size.

References

Abdullah, H., Bandyopadhyay, A. and Singh, S. (2009), "Laboratory assessment of shear strength of sand", *Proceeding of INDOROCK 2009*, Second Rock Conference, Delhi, February, 150-156.

ASTM D 1194-94 (2003), *Standard Test Method for Bearing Capacity of Soil for Static load and Spread Footings*, Annual Book of ASTM Standards, ASTM International, West Conshohocken, PA, USA.

Bolton, M.D. and Lau, C.K. (1989), "Scale effect in the bearing capacity of granular soils", *International Proceeding of the 12th International conference on Soil Mechanics and Foundations Engineering*, Rio De Janeiro, Brazil, 895-898.

Bolton, M.D. and Lau, C.K. (1993), "Vertical bearing capacity factors for circular and strip footings on mohr-coulomb soil", *Can. Geotech. J.*, **30**(6), 1024-1033.

Cerato, A.B. (2005), "Scale effect of shallow foundation bearing capacity on granular material", Ph.D. Dissertation, University of Massachusetts Amherst, 461.

Cerato, A.B. and Lutenegger, A.J. (2008), "Scale effects of shallow foundation bearing capacity on granular material", *J. Geotech. Geo-environ. Eng., ASCE*, **133**(10), 1192-1202.

Clark, J.I. (1998), "The Settlement and bearing capacity of very large foundations on strong soils: 1996 RM. Hardy keynote address", *Can. Geotech. J.*, **35**(1), 131-145.

Das, B.M. (1999), *Principals of Foundation Engineering*, International Thomson Comp., 155.

De Beer, E.E. (1965), "Bearing capacity and settlement of shallow foundations on sand", *International Proceeding of the Bearing Capacity and Settlement of foundations Symposium*, Duke University, Durham, NC, 15-34.

Hansen, J.B. (1970), *Revised and Extended Formula for Bearing Capacity*, Danish Geotechnical Institute, Copenhagen, Bulletin, **28**, 5-11.

Jacek, T. and Ivo, H. (1999), "Class a prediction of the bearing capacity of plane strain footings on sand", *Soil. Found.*, **39**(5), 47-60.

Jain, A., Dasaka, S.M. and Kolekar, Y.A (2010), "Lessons learned from failure of a field load test", *Proceedings of International Symposium on Forensic Approach to Analysis of Geo-hazard Problems*, 14-15.

Jain, A.K. (2011), "Effect of loading mechanism on plate load test results", M. Tech. Thesis, IIT Bombay.

Kumar, J. and Khatri, V.N. (2008), "Effect of footing width on bearing capacity factor N_γ for smooth strip footings", *J. Geotech. Geo-environ. Eng., ASCE*, **134**(9), 1299-1310.

Meyerhof, G.G. (1963), "Some recent research on the bearing capacity of foundations", *Can. Geotech. J.*, **1**(1), 16-26.

Moghaddas Tafreshi, S.N. and Dawson, A.R. (2009), "Comparison of bearing capacity of a strip footing on sand with geocell and with planar forms of geotextile reinforcement", *Geotext. Geomembr.*, **28**(1), 72-84.

Prandtl, L. (1921), "On the penetrating strengths (hardness) of plastic construction materials and the strength of cutting edges", *Zeitschrift fu Angewandte Mathematik and Mechanik*, **1**, 15-20.

Reissner, H. (1924), "Zum Erddruck problem (Concerning the earth–pressure problem)", *International Proceedings of the first International Congress of Applied Mechanics*, Delft, Germany, 295-311.

Terzaghi, K. (1943), *Theoretical Soil Mechanics*, John Wiley and sons, New York, USA.

Veiskarami, M., Jahanandish, M. and Ghahramani, A. (2011), "Prediction of the bearing capacity and load-displacement behaviour of shallow foundations by the stress-level-based ZEL Method", *Scientia Iranica*, **18**(1), 16-27.

Vesic, A.S. (1973), "Analysis of ultimate loads of shallow foundations", *J. Soil Mech. Found. Div., ASCE*, **99**(SM1), 45-73.

CC